CHARACTERISTIC TESTS OF SILICIDE FUEL CORE IN JRR-3M

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ABSTRACT

In JRR-3M, the core conversion works from the aluminide fuel to the silicide fuel had been conducted since September of 1999. In the core and the heavy water tank, four BF_3 counters and two CICs were installed so as to measure a small amount of neutron, and antimony was installed in the beryllium reflector as the neutron source. JRR-3M achieved the first criticality using the silicide fuels on September 17th, 1999. The minimum critical core was achieved with 15 standard fuel elements. The minimum critical mass was measured to 8.467 kg ^{235}U. This result of measurement agreed approximately with the result of calculation with the MVP code. After that, JRR-3M constituted the full core. As the result, the excess reactivity in JRR-3M core was measured to 14.1 %Δk/k. Beside, the neutron flux, the control rod reactivity worth, the heavy water dump effecting, the moderator temperature effecting and so on had been measured as the characteristic test with the core conversion. Several reactor physics parameters had been obtained by these tests.

1. INTRODUCTION

JRR-3 attained its first criticality in 1963 as the first domestic reactor using natural uranium and slightly enriched fuel. And JRR-3 was utilized for the production of RIs and so on till 1985. After that, JRR-3 started to modify in 1988 for improvement of performance, that is, higher neutron flux, establishment of the beam guide hall, installation of the cold neutron source etc. The modified JRR-3 (JRR-3M) attained its first criticality in March of 1990 as a high-performance multi-purpose research reactor and started operation for the joint utilization with maximum output of 20 MW in November of the year.

JRR-3M is a light water moderated and cooled, beryllium and heavy water reflected pool type research reactor using the LEU fuel formed in the MTR fuel elements. Core of JRR-3M is composed of 26 standard fuel elements, six follower fuel elements with the hafnium absorber and the beryllium reflector and the heavy water tank are installed around the core. Schematic diagram of JRR-3M is shown in fig. 1. The maximum output is 20MW and the maximum thermal neutron flux in the aluminide fuel core is 3×10^{14} n/cm^{2}sec. As a cycle is 26 days continuous operation, seven or eight cycles are conducted for a year.

JRR-3M had used the uranium-aluminum (UAl_x-Al) dispersion type fuel (aluminide fuel, enrichment: 20 %^{235}U, uranium density: 2.2 g/cm^3) since 1990. JRR-3M consumed all aluminide fuels by September of 1999. Total thermal power and total operation time using aluminide fuels are 688,720MWh and 36,614hours respectively.

2. PROJECT FOR CONVERSION OF SILICIDE FUEL

Stability of the silicide (U_3Si_2) fuel, whose enrichment was 20 %^{235}U and uranium density was 4.8 g/cm^3, was confirmed by the burnup stability test and so on during RERTR program. As the result, the fuel element of JAERI's research reactor, such as JMTR, JRR-4 and so on, using LEU plate type fuel has been converted into the uranium-silicon-aluminum (U_3Si_2-Al) dispersion type fuel (silicide fuel) with higher uranium density in recent year.

In JRR-3M, because of high net working rate, relatively much fuel had been consumed and many spent fuel elements have also been stored. As the merit of using silicide fuel, refueling period becomes longer because the silicide fuel element is possible to add more amounts of ^{235}U than the aluminide fuel element. In the case that JRR-3M continues to use the aluminide fuel element, it is possible to cause a problem of supply and making cost because of the aluminide fuel maker shortage.

Therefore, JRR-3M decided to convert the aluminide fuel into the silicide fuel in order to decrease the annual generation of spent fuel and to secure the fuel supply. And JRR-3M changed refueling scheme from the batch-refueling scheme, namely, 26 standard fuel elements were categorized into five groups and all fuel elements in a categorized group were refueled, to the burnup-management scheme, namely, some fuel elements were refueled to satisfy burnup limit of 60 %. And besides, cadmium wire was buried in the side plate of the silicide fuel elements in order to repress the initial excess reactivity, which was caused by increase of uranium loading amount. JRR-3M obtained the national permission for changing on January of 1998 and started to load the silicide fuel into the core since September of 1999. The comparison of aluminide fuel and silicide fuel is shown in table 1.

3. CHARACTERISTIC TESTS OF SILICIDE FUEL CORE

Characteristic test had been conducted from September 6th, 1999 to November 14th, 1999. In this characteristic test, the nuclear characteristic test was mainly conducted to ensure the safety reactor operation, because only fuel elements were changed. Main contents of this characteristic test consist of the critical approach test, the excess reactivity measuring test, the thermal neutron flux distribution measuring test, the control rod reactivity worth measuring test, the heavy water dump effectively test and so on. Timetable of these characteristic tests is shown in table 2. Results of typical tests were shown in the following.

3.1 Critical approach test

As the temporary neutron detector, four BF_3 counters were installed in the core and the beryllium reflector in order to measure the inverse multiplication factor and two CICs were installed in the heavy water tank in order to confirm the criticality. And irradiated antimony was installed in the beryllium reflector as the neutron source. Arrangement diagram of the temporary neutron detectors and a neutron source is shown in fig. 2.

After all aluminide standard fuel elements were converted into the dummy fuel elements on September 8th, six aluminide follower fuel elements were converted into six silicide follower fuel elements. Loading of the silicide standard fuel elements was started on September 13th. After that, while measuring the inverse multiplication, JRR-3M achieved the first criticality on September 17th, 1999. Measured inverse multiplication curve is shown in fig. 3.

The minimum critical core was achieved with 15 standard fuel elements and six follower fuel elements. In this situation, only a regulating control rod was pulled up to 77 % of full stroke and other control rods were pulled up to full stroke position. The minimum critical mass was measured to 8.467 kg ^{235}U. Effective multiplication factor was evaluated to 1.007 with MVP simulation code in the case of 15-standard-fuel-elements-core. Therefore, this result of evaluation agreed approximately with result of measurement. In the case of the aluminide fuel element, the minimum critical core was achieved with 15 standard fuel elements.

3.2 Excess reactivity measuring test

After the minimum critical was achieved, standard fuel elements were loaded one by one into the core while confirming not to achieve critical. And the full core of 26 standard fuels was constituted. The reactivity added with a fuel element loading was measured with the inverse kinetics (IK) method. Two CICs installed in the heavy water tank were used as neutron detector. The excess reactivity to number of fuel elements is shown in fig. 4.

The excess reactivity of full core, which was estimated as a total of the reactivity added with a fuel loading, was 14.1 %Δk/k. And calculated excess reactivity of full core by MVP code was 14.7 %Δk/k. Therefore, measurement in this characteristic test was approximately corresponded to analysis.

3.3 Thermal neutron flux distribution measuring test

The thermal neutron flux distribution in the fuel region was measured by the activation method with gold foil during output of 20 W operation. Four measured fuel positions were selected at center and edge of the core. Measured directions were vertical and horizontal.

Measuring point and results of measurement in the vertical direction are shown in fig. 5. As shown in the figure, a peek of neutron flux appeared at low position, because excess reactivity was higher under the initial core and control rods were inserted deeply. The shape of its distribution was approximately same as the aluminide fuel core. But value of the thermal neutron flux decreased to between 39 % and 62 % of the aluminide fuel. Averaged thermal neutron flux was 47 % of the aluminide fuel. Generally, the increase of uranium in the core causes the decrease of neutron flux in fuel region and hard neutron spectrum. And cadmium wires in the fuel plates also absorb the thermal neutron. Therefore, it is thought that the thermal neutron flux decreased relatively.

Measuring point and results of measurement in the horizontal direction are shown in fig. 6. As shown in the figure, thermal neutron flux increased near center of the core and beryllium reflector. The shape of its distribution was approximately same as the aluminide fuel core. The thermal neutron flux in the horizontal direction decreased to between 48 % and 69 % of the aluminide fuel. Averaged thermal neutron flux was 57 % of the aluminide fuel.

Result of analysis about neutron flux distribution in the fuel region was 40 % lower than the aluminide fuel core. Therefore, measurement of neutron flux in fuel region was approximately corresponded to analysis. And result of analysis about neutron flux distribution in the heavy water tank was approximately same as the aluminide fuel core.

3.4 Other characteristic tests

As other characteristic tests, the control rod reactivity worth measuring test, the heavy water dump effecting measuring test, the control rod drop test, the moderator temperature effecting measuring test and so on were conducted. These results are shown in table 3 with results of aluminide fuel core.

Control rod reactivity worth was measured with the inverse kinetic method. Reactivity worth of each control rods in the silicide fuel core are lower than the aluminide fuel core. However, it was confirmed that safety margin of control rod worth was enough.

Heavy water dump effectively was also measured with the inverse kinetic method. Heavy water dump effecting was 1.3 %Δk/k in approximately same as the aluminide fuel core.

Control rod drop test was conducted to measure the shutdown margin with the inverse kinetic method. Shutdown margin was 13.0 %Δk/k.

Moderator temperature effecting was -0.01 %Δk/k/°C.

4. CONCLUSION

According to the results of these characteristic tests on the silicide fuel core, it is concluded that the fuel conversion from the aluminide fuel to the silicide fuel has been successfully completed. And, results of measurement in characteristic tests were good corresponded to the analysis. The obtained data can be utilized for the operation and management of the JRR-3M with the silicide fuel core.

JRR-3M has been operated for capsule irradiation, beam experiment and so on by using the silicide fuel elements at full power of 20 MW since November 22, 1999. No troubles in fuel elements have been observed.

It is confirmed that annual generation of spent fuel decrease by this conversion work.

ACKNOWLEDGMENTS

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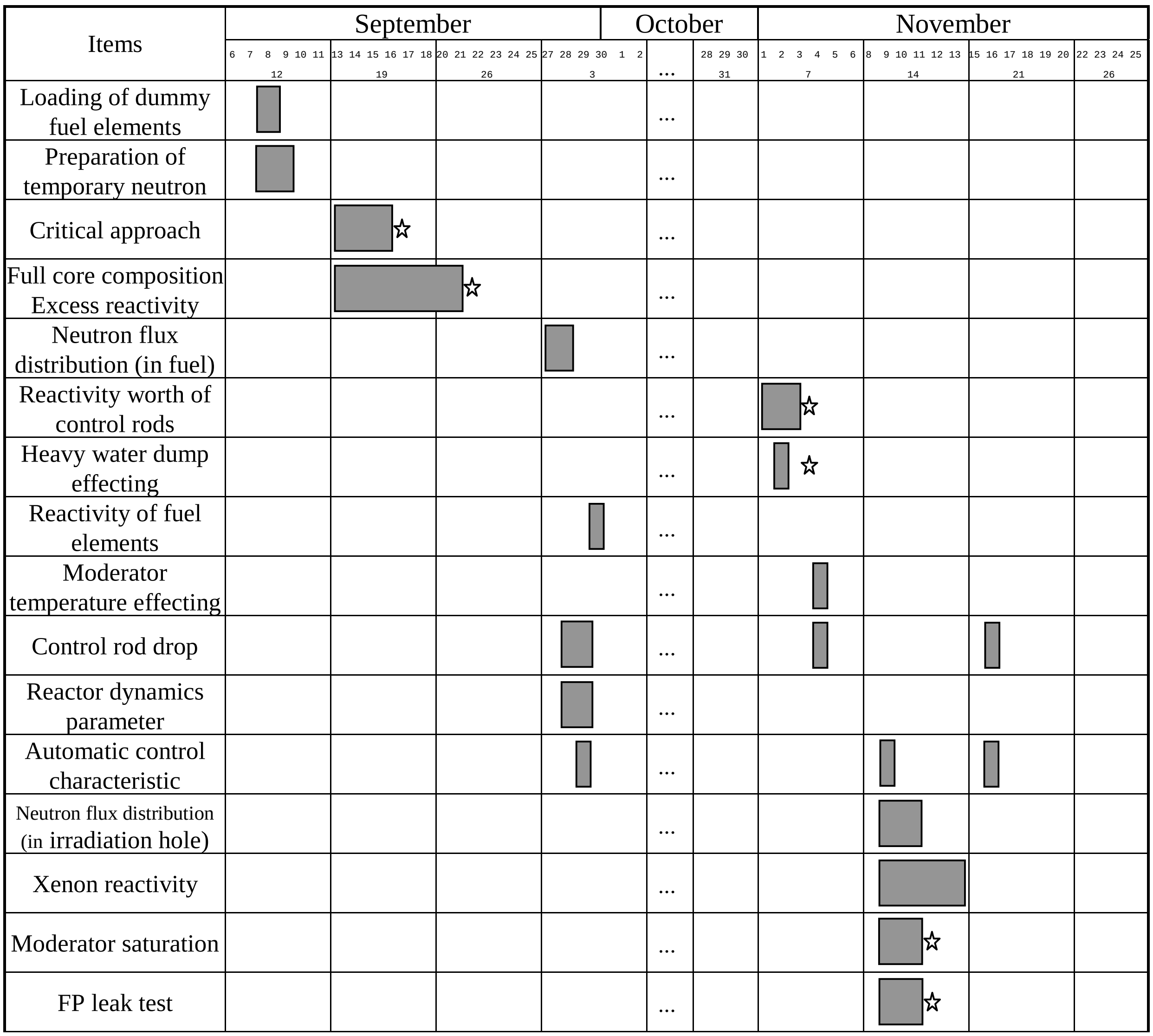
Table 1 Comparison between the aluminide fuel element and the silicide fuel element

Items	**Aluminide fuel**	**Silicide fuel**
Outward form	about 76×76×1150mm	
Enrichment of ^{235}U	about 20 wt%	
Density of uranium	about 2.2 g/cm^3	about 4.8 g/cm^3
Content by amount of ^{235}U	about 300 g	about 470 g
Fuel plate	about 1.52×71×770 mm	about 1.27×71×770 mm
Number of plates	20 (number / element)	21 (number / element)
Covering material	aluminum alloy	
Maximum burnup	50 %	60 %
Burnable poison	-	cadmium wire

Table 2 Timetable of conversion work



Decay heat removal					...					
Operation for joint utilization					...					

•:Inspection of the regulatory body

Table 3 Results of other characteristic tests with the aluminide fuel core

Items		**Silicide fuel core**	**Aluminide fuel core**
Control rods reactivity worth (%Δk/k) Limit value: >19.1 %Δk/k (total)	Sa-1	4.3	5.4
	Sa-2	4.6	5.8
	S-1	4.0	4.5
	S-2	3.9	4.7
	R-1	4.5	4.4
	R-2	3.7	4.4
	Total	25.0	29.2
Heavy water dump effecting (%Δk/k)		1.3	1.4
Control rod drop (%Δk/k)		13.0	
Moderator temperature effecting (%Δk/k/°C)		-0.01	-0.02

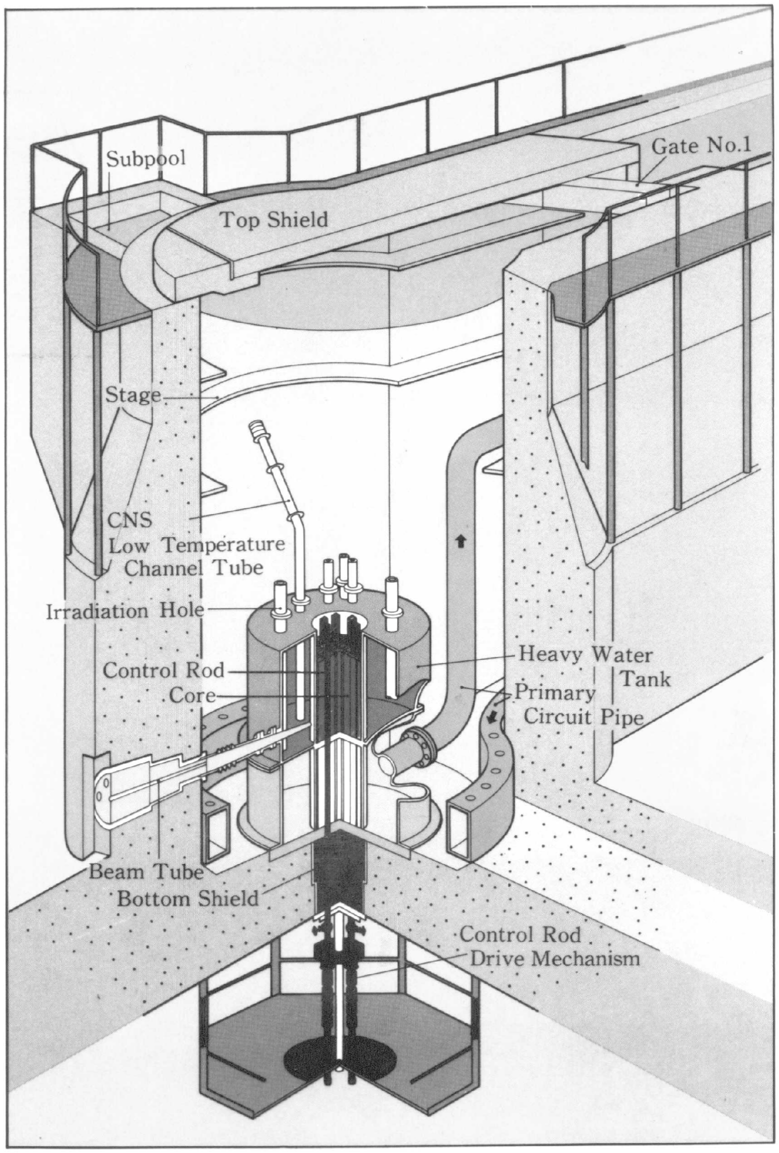
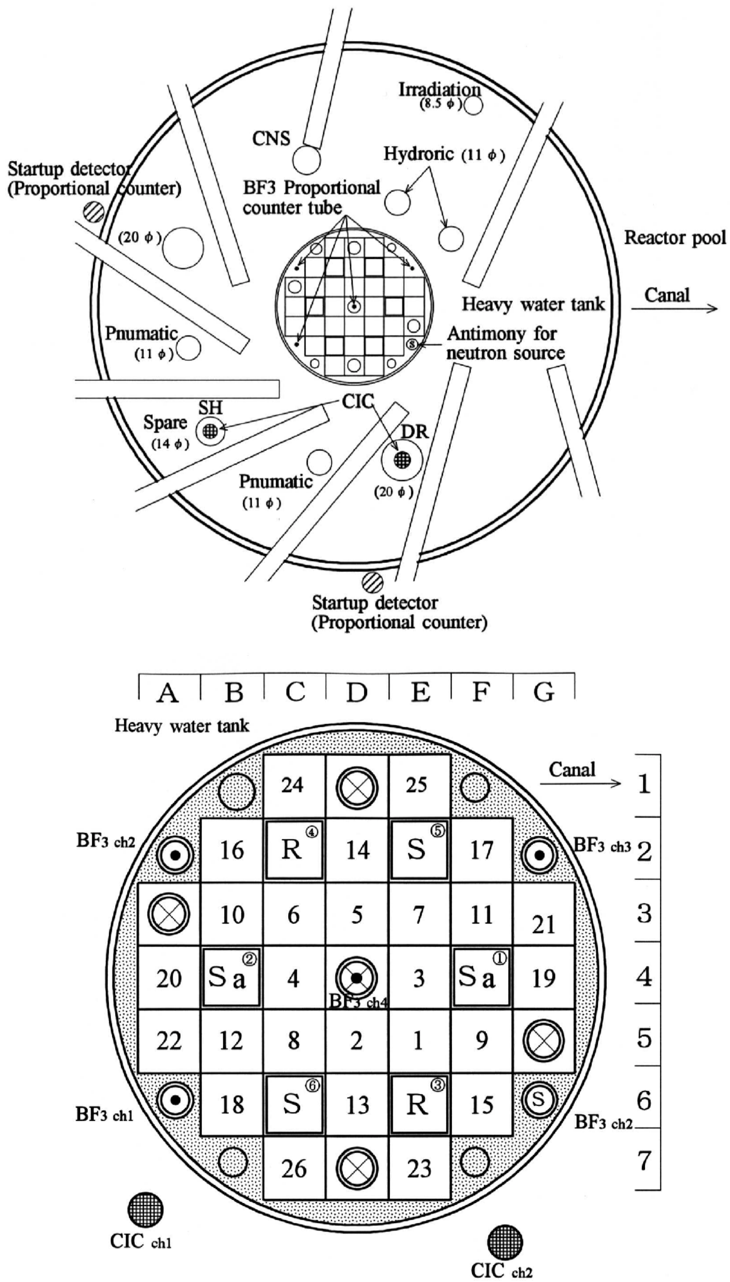


Fig. 1 Shematic diagram of JRR-3M



: Standard fuel element (number shows loading order)

: Plug (made of aluminium)

: Follower fuel element (number in • shows loading order) and control rod (R: for fine regurlation S,Sa: for general regulation)

: Irradiation hole (made of aluminium)

: BF_3 proportional counter tube

: Be reflector

: Be plug

Fig. 2 Configuration of temporary neutron detecter and neutron source

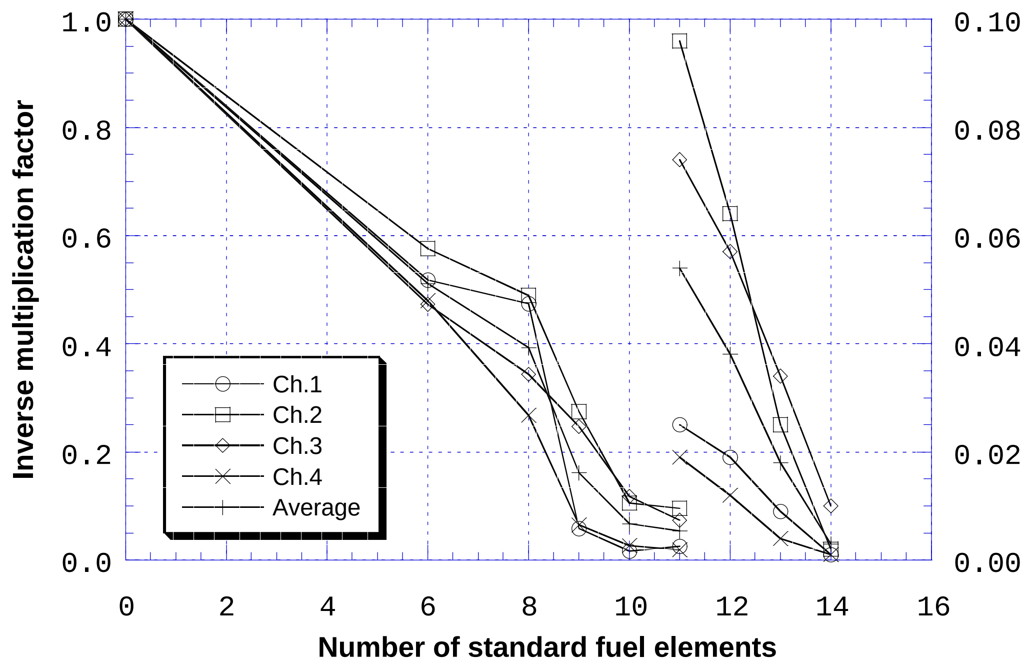


Fig. 3 Result of measured inverse multiplication (1/M curve)

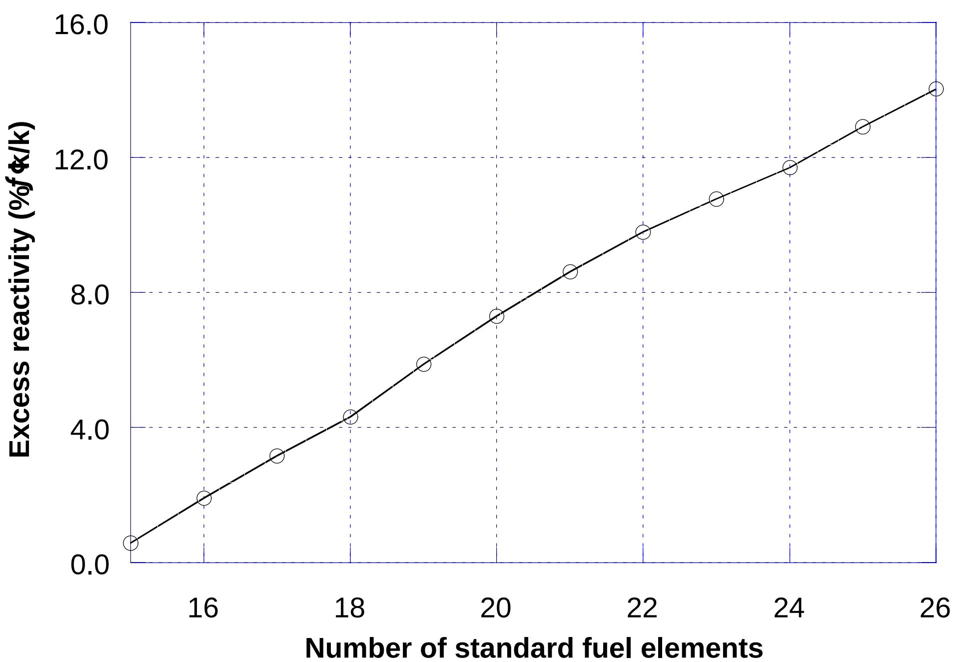


Fig. 4 Excess reactivity to number of fuel elements

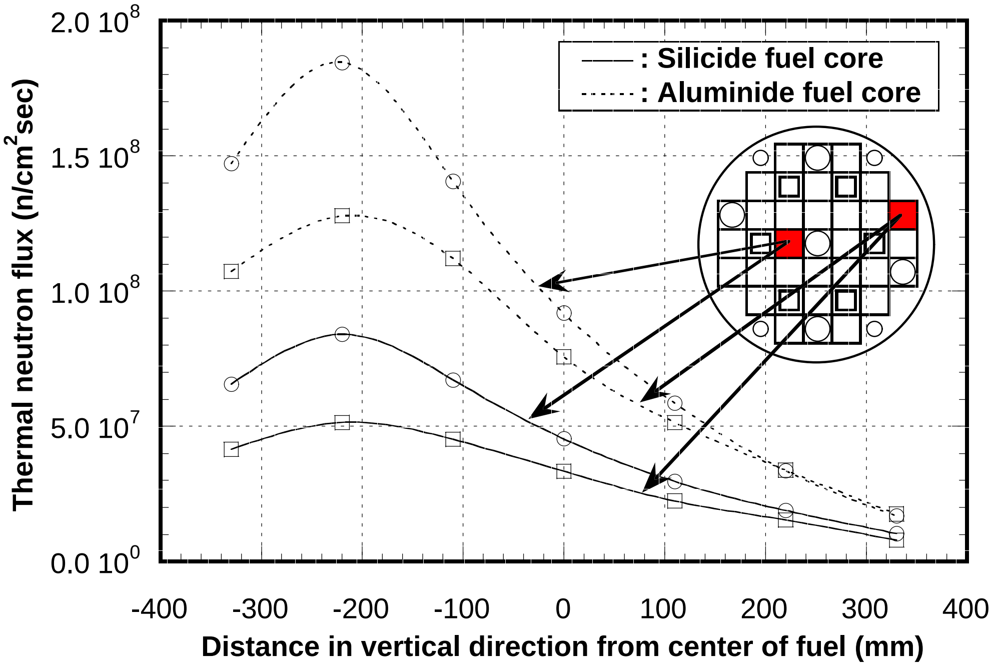


Fig. 5 Thermal neutron flux distribution in vertical direction in the fuel region (20W operation)

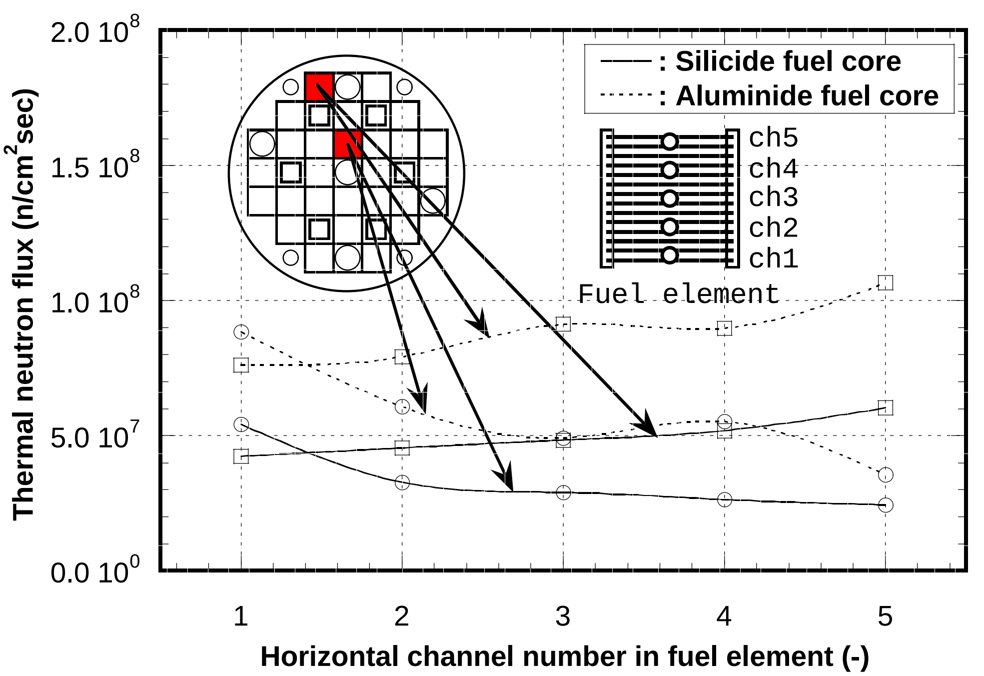


Fig. 6 Thermal neutron flux distribution in horizontal direction in the fuel region

(20W operation)